Fault and Natural Fracture Identification from Multicomponent Seismic at Rulison Field, Colorado

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Introduction

Cumella and Ostby (2003) and many others have published fault interpretations in the Piceance Basin. There are two significant differences between these past interpretations and this one. First, this fault interpretation is primarily from the slow shear (S2) volume. This volume was chosen after carefully comparing and evaluating the p-wave, converted wave, and shear wave volumes, the S2 volume drastically stood out as the volume with the least noise and most interpretable information. The second difference is that the main fault interpretation made here is perpendicular to the trend of the majority of the previously interpreted deep, below reservoir, field scale faults.

Faulting

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Figure 6 shows a deep fault that has splayed at a lower level and propagated up through the reservoir. This fault was not apparent in the p-wave data and appeared to have tipped out at this depth. The S2 volume resolves the fault and the splay at this level and through most of the reservoir revealing other resolvable splay faults and a flower structure fault in the reservoir. The main deep fault splay from the lower reservoir level up into the main reservoir. This fault is joined through the reservoir interval as a 3-D fault plane with 3 splays. Figure 7 shows a 3-D image of the fault planes from the below the reservoir zone where only the main fault and propagating through the reservoir is visible. The images confirm that the main fault splay from the high angle fault plane into the field plane. The movement on these faults is interpreted to be left lateral with very little vertical reverse movement. This type of faulting is best fit the model of a strike-slip flower structure fault.

Faulting (Continued)

Multicomponent seismic has not traditionally been used in unconventional tight gas sand reservoirs. Rulison Field, Piceance Basin, Colorado is a thick tight gas sand reservoir that is heavily faulted and fractured. This field was chosen because of these characteristics by the Reservoir Characterization Project (RCP) research consortium at Colorado School of Mines to research the ability of multicomponent seismic to detect faulting and natural fracturing. This paper presents the results of this research from the nine component 3-D seismic survey that was acquired in the field in 2003. One of the main goals of this research is to use the multicomponent seismic to optimize natural gas production in the field. Natural gas production in this area of the Piceance Basin is known to be controlled by natural fractures. Therefore, finding the naturally fractured zones is one of the main ways to optimize production in this field. The natural fracture density increases near reservoir faults which makes locating the faults equally important. Identifying reservoir overlap and fluid flow from traditional p-wave survey has been relatively unsuccessful in the past. This research uses multicomponent seismic for structural fault interpretation and s-wave splitting analysis for natural fracture identification.

Faulting (Continued)

Figure 7 shows the intersection of well Wall 1. Wall 1 has image and anisotropy logs that have been interpreted for faults and fractures. The yellow fault cuts Well 1 at a depth that the s-wave splitting calculations were done on seismic volumes as opposed to the traditional horizon-based approach. This process resulted in s-wave splitting volumes that correlate with image log fractures and anisotropy logs from cross-dipole sonic logs. These volumes show spacial and vertical variations in the degree of s-wave splitting that are geologically reasonable and can ultimately be used to optimize well locations and drilling efficiency.

Summary

Shear-wave seismic acquired at Rulison Field, Piceance Basin, Colorado in 2003 exhibits evidence of faults and natural fractures from reflection discontinuity and shear-wave splitting analyses. Rulison Field is a thick unconventional natural gas reservoir produced from the fluvial light gas sandstones of the Late Cretaceous Williams Fork Formation. Fault interpretations made from Multicomponent seismic data clearly show near vertical faults in the lower reservoir Cameo Coal interval that strike in a north-northwest direction. The shear-wave (s-wave) seismic shows better quality waveforms for the s-wave data than the p-wave. Barehole image logs confirmed these faults. These faults splay up into the reservoir creating flower structures that create fault zones and control natural fracturing within the reservoir.

Natural fractures were observed from s-wave splitting. Since the reservoir is more than a wavelength thick, s-wave splitting calculations were done on s-wave volumes as opposed to the traditional horizon-based approach. This process resulted in s-wave splitting volumes that correlate with image log fractures and anisotropy logs from cross-dipole sonic logs. These volumes show spacial and vertical variations in the degree of s-wave splitting that are geologically reasonable and can ultimately be used to optimize well locations and drilling efficiency.

Faulting (Continued)

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S-wave splitting analysis is a proven technique that is typically able to detect fractures large enough to create seismic scale anisotropy and is typically done once the S2 volume was shifted into S1 time by the time difference calculations, volumetric differencing of impedance inversion volumes was calculated. The resulting volume is an impedance anisotropy volume that shows areas of high anisotropy where natural fracture zone exist. Since amplitude anisotropy is a higher resolution tool than time anisotropy, these volumes, which are created from impedance volumes in the similar way as time-based amplitude volume maps, are much more likely to accurately correlate to the well data through the reservoir level than the time anisotropy volumes. The primary drawback in calculating the impedance anisotropy is the resulting volume is not well matched in time. In the middle of the reservoir, the time shifting is not always perfect. However, the inability of the time shifting algorithm to match these areas just points out that these areas are anisotropic. Calculating the volumetric impedance anisotropy in these areas will result in high impedance anisotropy values because the reflectors are not perfectly matched.

Figure 14 shows a line of the impedance anisotropy volume at the location of well 2 with the smoothed anisotropy log from well 2 displayed. The color bar for the anisotropy seismic line and the amplitude anisotropy seismic line and the amplitude anisotropy volume at the reservoir level. Notice that the three wells with high EUR values are high in all three low EUR wells and ties well to the image and anisotropy logs. This means that there is a 100% accuracy to the similarity difference volume detected known fractured areas best and has the potential ability to predict naturally fractured areas.